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3.2.2 Hydration

3.2.2.1 Definition and Measurement

Proper hydration is essential for optimal human performance. Euhydration refers to "normal" total body water (TBW), whereas hypohydration refers to a body water deficit. The term dehydration is used to refer

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3.2.2.2 Background

Adequate hydration is essential for maintaining fighting effectiveness, and several common operational stresses can result in relatively large alterations in TBW content and distribution. During most "normal" conditions, humans have little trouble maintaining optimal fluid balance. However, many factors such as sickness, physical exercise, climatic exposure (heat, cold, and altitude), and psychological strain can lead to significant disturbances in water balance (Sawka, 1988). Perhaps the best example involves heat stress and physical activity. For sedentary persons in temperate conditions, water requirements usually range from 2 to 4 L per day, and the kidneys primarily regulate fluid balance. For physically active persons who are exposed to heat stress, water requirements can often double (Sawka, Montain, & Latzka, 2001).

Water is the largest single constituent of the body (50 – 70% of body weight) and is essential for supporting the cardiovascular and thermoregulatory systems, and cellular homeostasis. TBW is distributed into intracellular fluid (ICF) and extracellular fluid (ECF) compartments. Exercise-heat stress not only stimulates fluid loss (primarily through sweating) but also induces electrolyte imbalances and renal function changes. As a result, fluid losses and gains with and without proportionate solute changes can occur. In addition, exercise-heat stress will alter transcompartmental and transcapillary forces that redistribute fluids between various compartments, organs, and tissues (Sawka et al., 2001). For these reasons, the accuracy of most methods used to assess hydration status is highly limited by the circumstances in which the measurements are made and the purposes for which they are intended.

TBW is the "gold standard" measurement to assess hydration status (Aloia, Vaswani, Flaster, & Ma, 1998; Lesser & Markofsky, 1979). TBW can be directly measured with doubly labeled water (DLW) and other dilution techniques. However, the requirement for expensive equipment and the associated technical problems make the use of these methods impractical. Although the choice of biomarker for assessing hydration status should ideally be sensitive and accurate enough to detect relatively small fluctuations in body water, the practicality of its use (time, cost, and technical expertise) is also of significant importance.

3.2.2.3 Effect on Performance

Both physical and cognitive performance are impaired proportionally to the magnitude of body water loss incurred (Sawka, 1988), but even small losses of body water (1 – 2% of body mass) have a measurable detrimental impact on physical work and negatively impact thermoregulation (Sawka, 1992; Sawka & Coyle, 1999).

3.2.2.4 Assessment Methods

Estimates of hydration are commonly made using (1) bioelectrical impedance analysis, (2) plasma indices, (3) urinalysis, and (4) changes in body weight. Given consideration to military field operational use, hydration assessment measurements are presented in order of increasing accessibility and practicality. Table 10 summarizes the advantages and disadvantages of each method.

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Table 10: Biomarkers of Hydration Status

Measurement	Advantages	Disadvantages
Bioelectrical Impedance Analysis	Non-invasive Quick assessment	Measurements confounded by posture, diet, temperature, and fluid & electrolyte concentrations Invalid to assess hydration changes
Plasma Indices	Reliable for hyperosmotic dehydration and hyponatremia	Invasive measurement Moderately complex instrumentation
Urinalysis	Quick assessment Reliable measure 1st morning urine (U_{osm} and USG) Valid for screening of dehydration if combined with other indices	Unreliable for tracking acute changes in hydration Color influenced by diet, multivitamins, and medications
Body Weight	Quick assessment Simplest technique Easy to track in field exercises	Unreliable overtime due to changes in body composition (mass from lean body tissue)

3.2.2.4.1 Bioelectrical Impedance Analysis

Recently, bioelectric impedance analysis (BIA) has gained attention because it is simple to use and provides rapid, inexpensive, and non-invasive estimates of TBW (O'Brien, Young, & Sawka, 2002). Total body water volume is directly proportional to impedance (Berneis & Keller, 2000; Kushner, 1992; O'Brien et al., 2002). In practice, a small constant current is passed between electrodes spanning the body and the voltage drop between electrodes provides a measure of impedance (Kushner, 1992).

BIA does not have sufficient accuracy to validly assess moderate dehydration (~7% TBW) and loses resolution with isotonic fluid loss (O'Brien et al., 2002). In addition, since fluid and electrolyte concentrations can have independent effects on the BIA signal, the measurement can often provide grossly misleading values regarding hydration status (O'Brien et al., 2002). BIA has little application for the field assessment of hydration status.

3.2.2.4.2 Plasma Indices

Plasma volume decreases with dehydration; however, this response varies as a function of the type of dehydration (iso-osmotic or hyper-osmotic), physical activity, and the individual's heat acclimatization status and physical fitness (Sawka, 1988). Plasma volume changes can be estimated from hemoglobin and hematocrit changes; however, accurate measurement of these variables requires considerable controls for posture, arm position, skin temperature, and other factors (Sawka, 1988). If adequate controls are employed, plasma volume decreases proportionally with level of exercise-heat mediated dehydration.

In heat-acclimated persons undergoing exercise-heat mediated dehydration, resting plasma volume decreases in a linear manner that is proportional to the water deficit (Sawka & Coyle, 1999). These same levels will be maintained during subsequent physical exercise. If an iso-osmotic dehydration occurs, such as with altitude or cold exposure (O'Brien, Young, & Sawka, 1998; Sawka, 1992), then plasma osmolality changes will not follow TBW changes, and much larger plasma volume reductions will occur. The measurement of plasma osmolality and sodium requires phlebotomy (invasive), technical skill, and expensive instrumentation.

3.2.2.4.3 Urinalysis

Urinalysis is a frequently used clinical measure to distinguish between normal and pathological conditions. Urinary markers of hydration status include urine specific gravity (USG), urine osmolality (U_{Osmol}), and urine color. Urine specific gravity and osmolality are quantifiable and threshold values can provide some meaningful interpretation, whereas color is subjective and can be influenced by many factors including diet. It is important to recognize that the accuracy of these urinary indices in assessing chronic hydration status is improved when the first morning urine is used due to a more uniform volume and concentration (Sanford & Wells, 1962; Shirreffs & Maughan, 1998). Likewise, many factors such as diet, medications, exercise, climatic exposure, and timing can confound these indices.

The most widely used urine index is USG, measured against water as a standard (1.000 g/ml). Because urine is a solution of water and various other substances, normal values range from 1.010 to 1.030 (Armstrong et al., 1994; Popowski et al., 2001; Sanford & Wells, 1962). It has been suggested that a USG $\leq$ 1.020 represents a state of euhydration (Armstrong et al., 1994; Popowski et al., 2001). As a measure of chronic hydration status, USG appears to accurately reflect a hypohydrated state when in excess of 1.030 (Francesconi et al., 1987; Adolph, 1947; Armstrong et al., 1994; Popowski et al., 2001). However, considerable variability exists and no singular value can be used to determine a specific hydration level. U_{Osmol} also can provide an approximation of hydration status (Shirreffs & Maughan, 1998) since it is highly correlated with USG (Armstrong et al., 1994; Popowski et al., 2001), but the values are more variable.

3.2.2.4.4 Body Weight

Body weight (BW) measurements represent the simplest technique for rapid assessment of changes in hydration status. In our laboratory, we observe very small (< 1%) fluctuations in first morning BW when measured over consecutive days in young men taking food and fluid *ad libitum*. The stability of this measurement, coupled with the known losses of fluid that occur with exercise-heat exposure (primarily eccrine sweat), allows rapid changes in BW (incurred over hours) to be correctly attributed to water loss. Acute changes in BW are therefore a popular and reasonable field estimate of dehydration (Cheuvront, Haymes, & Sawka, 2002).

The level of dehydration is expressed as a percentage of starting body weight [(ΔBW/startBW) $\times$ 100] rather than as a percentage of total body water (TBW) since TBW ranges from 50 – 70% of body weight. This technique assumes that (1) starting BW represents a euhydrated state, and (2) 1ml of sweat loss represents a 1g change in weight (i.e., the specific gravity of sweat is 1.000 g/ml). As an acute measure, first morning BW is still limited by changes in bowel habits. BW is also limited as a tool for long-term assessment of hydration status since changes in body composition (fat and lean mass) that occur with chronic energy imbalance are also reflected grossly as changes in BW. Clearly, the use of daily body weight should be used in combination with another hydration assessment technique (first morning urine) to dissociate gross tissue losses from water losses if long-term hydration status is of interest.

3.2.2.5 Practical Applications

Under most conditions, day-to-day body mass changes (<2%) and first morning urine specific gravity (<1.030) when used together provide an approximate indication that an individual is dehydrated (see Table 10). However, plasma osmolality changes can provide more reliable information regarding hydration when greater precision is required. Moreover, BIA should not be used to assess hydration status in the field for reasons previously described. It is possible that other technological advances may allow evaluation of other measures (e.g., muscle water content) that hold promise as hydration indices.

The views, opinions, and/or findings contained in this publication are those of the authors and should not be constructed as an official Department of the Army position, policy, or decision unless so designated by other documentation.

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3.2.3 Illness

3.2.3.1 Definitions

By their very nature, illnesses produce performance decrements in afflicted individuals. While severe symptoms may lead to bed rest and even hospitalization, individuals with less severe symptoms may continue to work. Besides the risk of spreading their illness to co-workers, ill workers may not perform their jobs at the levels realized when they are healthy. This not only lowers their efficiency, but, in some cases, may also result in errors that put themselves, co-workers, and the systems they operate in jeopardy. Severe chronic illnesses are usually not of concern to day-to-day operations because these individuals are aware of their conditions and do not work beyond their capabilities. Of concern are rapid onset illnesses such as heart attacks that may occur at the work place, and more transient illnesses such as colds, whose symptoms may be judged by the ill person to not be serious enough to warrant missing work. In operational situations, it is possible that the performance consequences of these minor illnesses may be judged inconsequential and the ill individual is expected to work. Closer examination of some of these minor illnesses shows that performance may be affected.

It has been estimated that 10 to 12 percent of all work absences are due to colds and influenza (Smith, 1992). It is well known that many individuals with colds still report to work. The motivation behind working when ill varies, but, nevertheless, working while ill can be associated with sub-par work performance. This performance reduction may also result in accidents and errors that can affect others. The onset of illness may prompt individuals to seek relief from symptoms through the use of over-the-counter (or prescription) medications, which often produce side effects that also degrade performance. The job environment itself may induce transient illness in some individuals. For example, debilitating motion sickness, simulator-induced vertigo, and virtual reality-induced vertigo may occur in healthy individuals and may be induced by the work environment (Bullinger, Bauer, & Braun, 1997; Griffin, 1997). Other illnesses of interest brought about by occupational activities include dehydration and acute mountain sickness.

Because the level of performance degradation and the particular cognitive modality affected varies, it is difficult to construct general guidelines concerning whether or not a given individual should work when ill. Probably the most widespread of the minor illnesses that have been shown to produce performance effects are the common cold and influenza. Not only do the symptoms of these two illnesses differ, but their effects on performance also differ.

3.2.3.2 Background

Ill individuals typically suffer performance decrements. The effects of these decrements can vary from minor to catastrophic. Furthermore, in the case of major illnesses, the performance of co-workers can be influenced. For example, a severe cardiac episode can disrupt normal procedures and lead to behavior that is disruptive of co-worker performance. This can be especially serious in certain jobs that involve the well being of others such as aircraft crews. Ill pilots are not only incapacitated so that they are not able to perform their duties but their illness distracts other crew members from properly performing their duties, which can lead to serious consequences (Baker, 1999).

3.2.3.2.1 Chronic vs. Acute Illness

Common colds and influenza are much more prevalent in the work place than are catastrophic illnesses. As such, they probably represent the most widespread illnesses with which operators still report to work